Advanced Combustion Technologies for Mobile and Stationary Engines

We are developing technologies to improve the efficiency of internal combustion engines and to reduce harmful emissions from the engine exhaust.

We are drawing upon Livermore's multidisciplinary capabilities to develop ways of increasing engine efficiency, thus saving fuel, while reducing the emissions that adversely affect the environment. Our efforts focus on analyzing alternative fuels, optimizing engine design, and applying innovative tools to clean the exhaust stream.

Underlying much of this work is the Laboratory's unique capability in chemical kinetic modeling, which uses computer simulation to determine how, when, and where combustion occurs within an engine and which chemical reactions take place.

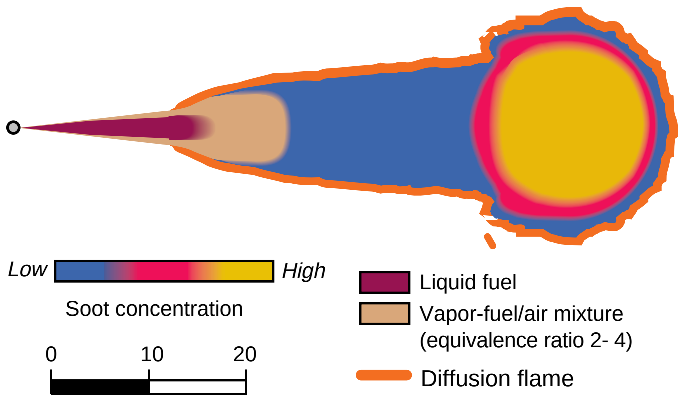
Sponsors for this work include industry, the Department of Energy, and the Department of Defense.

Alternative Diesel Fuels: Looking at Soot Production

In collaboration with several engine companies, we have been using these computer simulation techniques to study ignition and soot production in advanced diesel engines. Our chemical kinetic models examine how fuel molecular structure influences emissions. (Normal diesel fuel is a mixture of complex molecules with as many as 50 or more atoms.)

We are analyzing some alternative fuels—such as dimethyl ether and dimethoxy methane—that have been suggested to reduce soot and NOx emissions from diesel engines. These fuels contain no carbon-to-carbon bonds and produce little or no soot; and, like other fuels containing oxygen atoms such as alcohols and ethers, they reduce NOx emissions by lowering flame temperatures. We are using our chemistry models to understand and exploit these properties.

Our models are also being used to study ignition in both spark-ignited and diesel engines (where ignition occurs by compression) to learn how these processes vary with fuel size and structure. These models are the most complex and detailed mechanisms available to study the chemical reactions of practical automotive fuels such as gasoline and diesel fuel.



Chemical kinetic modeling schematic showing concentrations of soot in the first part of a mixing-controlled burn in a diesel engine. Artwork: John Dee/Sandia

Designing More Efficient Engines

We are exploring an innovative engine concept—Homogeneous Charge Compression Ignition (HCCI)—that promises to operate at high efficiency (greater than 40%) with low NOx emissions. In an HCCI engine, the fuel is premixed with air, as in a spark-ignited engine, but in a very "lean" mixture that has a high proportion of air to fuel. When the piston reaches its highest point, the fuel autoignites from compression, as in a diesel engine.

Mobile Applications

- Light-duty and medium-duty vehicles
- Heavy vehicles (trucks, buses)
- Locomotives

Stationary Applications

- Generator sets
- Uninterruptible power supply
- Load leveling
- Distributed generation

Using our chemical kinetics code, we have proved that this concept will work by learning what happens chemically and by exploring the ignition timing, burn duration, and NOx production at various compression ratios. Now we are working to verify this concept experimentally, using natural gas as the fuel.

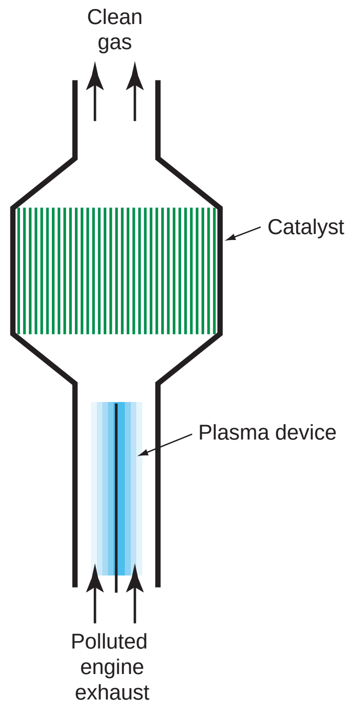
In other recent engine work, we designed and tested an engine to run on hydrogen fuel. Our goal was to get the most work per unit of fuel by designing for minimum heat transfer losses and timing losses, while also keeping emissions to a minimum. This engine, probably in a three-cylinder form, would be suitable for constant-speed, constant-load situations, such as series hybrid-electric automobiles or home cogeneration systems. When driving a generator, it represents a low-cost alternative to the fuel cell.

Reducing NOx Emissions from Lean-Burn Engines

Lean-burn engines are being viewed as one way to increase efficiency and burn less fuel, both in conventional gasoline engines and in diesel engines. However, because of high exhaust oxygen levels, lean-burn fuel mixtures create problems for catalytic converters now being used to reduce NOx emissions. Either the oxygen dominates available conversion sites, thus slowing the NOx conversion reactions, or the catalysts have poor durability.

Based on our experience in plasma physics and power supply technology, we have developed a process, Plasma Assisted Catalytic Reduction, that may solve this problem. We use a plasma device—essentially a metal wire, charged by a high-voltage pulsed power system, within a metal cylinder—to electrify the exhaust gas stream and break up the molecules as a “pretreatment” before the exhaust gas goes through a conventional lean-NOx catalyst.

Changing the exhaust gas into plasma form converts NO molecules into NO_2 before the exhaust stream enters the catalyst, where the NO_2 molecules are then efficiently converted to benign N_2. Unlike conventional lean-NOx catalysts, the NOx reduction efficiency of plasma-assisted catalysts does not degrade in the presence of sulfur in the fuel.



The plasma device oxidizes NO and hydrocarbons to NO_2 and partially oxidized HCs before the exhaust stream goes to the catalyst, which reduces NO_2 and HCs to N_2, CO_2, and H_2O.

We have developed a bench-scale prototype of this plasma-assisted converter and have successfully run tests on the slipstream of the exhaust from an actual diesel engine and also on the controlled laboratory gases that simulate exhaust mixtures. We are now scaling the system up to handle the full exhaust flow from car and truck engines.

Such a system could potentially be applied to various types of vehicles with lean-burning engines, using either gasoline or diesel fuel, and also to diesel generators.

Contact: Frank Tokarz
Lawrence Livermore National Laboratory
P.O. Box 808, L-644
Livermore, CA 94551
Phone: (925) 423-3459
Fax: (925) 423-7914
email: tokarz1@llnl.gov

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